DETERIORATION OF CONCRETE BLOCK PAVEMENTS

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SUMMARY

In South Africa crushed aggregates sourced from mining operations are often used to manufacture paving blocks. These aggregates are invariably of a high strength, but they contain variable quantities of inherent impurities that may affect the performance. A study was executed in the Free State province to identify the mechanism of deterioration of paving blocks. The aim of this paper is to evaluate the deterioration and to recommend remedial measures. Five different sites ranging in age from 1 to 15 years, as well as new blocks were evaluated. It was found that blocks that had deteriorated had a lower density and thus a weaker strength than the blocks that performed well. It was also found that chemical constituents in the rock could form sulphuric acid in a suitable oxidising environment. Historically a higher ordinary Portland cement content was used, but since cement is a major cost item, reduced quantities and blended cements are used, which aggravate the situation. It was recommended that to counteract the potential effects of acid formation, the cement content, and thus alkaline materials to neutralise the effects of the acid, should be used. Changing the source of aggregate was not an option, and pre-treatment could not neutralise the bound impurities. This investigation approach could also be used when waste products with unknown constituents are used for making paving blocks.

1. INTRODUCTION

In South Africa crushed aggregates sourced from mining operations are often used to manufacture paving blocks. These aggregates are invariably of a high strength, but they contain variable quantities of inherent impurities that may affect the performance, particularly quartzite aggregate sourced from the gold mines. The type of deterioration that has been found on paving blocks is surface degradation such as shown in Figure 1. Not all the blocks deteriorate, but only some, and often in patches, which suggest that these are related to the same production batch. This type of surface deterioration has been previously reported on paving blocks used in a marine environment (Visser, 2003). The current problem was found in the Free State province in South Africa; this province is located on the central plateau, and is more that 400 km from the coast.

The study focussed on the Free State province, but the findings are not restricted to this geographical area. The aim of this paper is to identify the mechanism of deterioration of paving blocks and to recommend remedial measures. The study evaluated five sites that ranged in age from 1 to 15 years. Newly produced paving blocks were also tested. At each site sound and deteriorated paving blocks were removed for laboratory testing to identify differences in properties that could explain the differences in performance.

2. CHEMICAL CONSTITUENTS OF QUARTZITE AGGREGATE

Quartzite aggregate obtained during gold mining operations contains pyrite in the form of iron pyrite, marcasite and chalcopyrite (Weinert, 1980). These are sulphides of iron. Pyrite is often known as



Figure 1. Surface deterioration of paving blocks at Welkom Club parking area after 8 years

fools gold as it has a cubical form and a gold colour which may be mistaken for gold. The pyrites decompose easily and fast once they are exposed to air and water, and the decomposition is aggravated if, in addition, bacterial action occurs (Weinert, 1980). During the decomposition of the pyrites, there is an intermediate stage where free sulphuric acid is present before the final decomposition products, the sulphate salts, are formed. ASTM C294-04 reports that certain forms of pyrites are reactive in mortar and concrete, producing a brown stain (from the iron) accompanied by a volume increase that has been reported as one source of pop outs in concrete.

In an earlier study by Oberholser (2004) it was found that the sulphate reaction products present in the crusher sand used for making paving blocks were either completely absent or present in very low quantities in samples collected from the crusher sand stockpiles. Therefore the deterioration of concrete due to the reaction between the cement and the sulphate present in the aggregate was not envisaged. The total sulphate content was well below the maximum limit by BS EN1260:2002.

These initial indications provided a challenge as to the source of the problem, as the answer was not immediately evident.

3. EXPERIMENTAL PROGRAMME

At five sites listed in Table 1 sound and deteriorated blocks were removed. These sites ranged in age from 1 to 15 years, and were used in a variety of applications, as shown in the Table. New blocks from the factory were also evaluated. All the blocks were made to have a 25 MPa compressive strength. A structural evaluation was also performed at each site, but since the focus of this paper is on the surface deterioration the structural aspects will not be dealt with.

Table 1. Description of study sections

Site	Age	Usage	Visual condition
Welkom Club	8yrs	Parking	Good riding quality
Industrial area	2yrs	Loading bay	Very bad condition
Oppenheimer Club	15yrs	Parking	Good condition
Agricultural road	1yr	Heavy vehicles	Variable
Slipway road	15yrs	Secondary road	Very good for age
New blocks	4 weeks	Unused	Very good

The following laboratory tests were executed on sound and deteriorated paving blocks from each site:

- Compressive strength test
- Tensile splitting strength test
- Water absorption
- Carbonation test
- X-ray fluorescence (XRF) spectroscopy analysis and X-ray Diffraction (XRD)
- Cement content
- Acid base test

3.1 Compressive strength test

The compressive strength was determined after soaking for 24 hours following the SABS1058:2002 method. Hardboard with a thickness of 3 mm was used between the block and the anvils in the crushing test. The compressive strength results in Table 2 represent a group of 12 blocks. It is

Table 2. Compressive strength and tensile splitting strength results

	Compressive strength (MPa)			Tensile splitting strength (MPa)		
SITE	**Maximum**	**Minimum**	**Average**	**Maximum**	**Minimum**	**Average**
Welkom SOUND	38.9	22.6	28.9	2.03	1.16	1.68
Welkom DET	17.7	9.6	13.4	3.35	1.00	1.62
Industrial SOUND	39.2	18.0	31.1	3.86	2.46	3.10
Industrial DET	25.5	11.4	18.9	2.29	1.61	1.96
Oppenheimer SOUND	60.2	37.4	44.0	3.31	2.54	2.95
Oppenheimer DET	37.4	8.8	27.1	1.67	1.16	1.41
Agricultural SOUND	42. 3	24.7	32.9	5.48	3.27	3.93
Agricultural DET	40.9	13.7	24.8	4.46	1.78	2.59
Slipway SOUND	44.3	24.2	39.0	7.94	5.52	6.61
Slipway DET	47.3	25.6	35.4	4.54	2.29	3.68
New	35.2	23.2	26.5	4.60	2.85	3.25

noticeable that on average the deteriorated blocks had much lower strengths than the sound blocks. Since separation into the two groups was done visually, it was possible for individual blocks to have the strength of the other group.

3.2 Splitting tensile strength test

This test was executed according to SABS1253:1994 after 24 hours of soaking. Hardboard strips 3 mm thick and 20 mm wide were placed under and on top of the block between the loading jig. This is to cause the fracture at right angles to the chosen plane.

The results from four block groups are given in Table 2. As in the case of the compressive strength, the deteriorated blocks had a lower splitting tensile strength than the sound blocks. As this is not part of the specification, there are no minimum standards for comparison.

3.3 Water absorption test

Before strength testing the mass of the soaked block was measured. After the strength test the pieces of the sample were placed in a plastic bag for oven drying at 70°C for at least 24 hours. The loss in mass divided by the dry mass of the block was the absorbed water. These results are considered in Section 4. There are no target values for water absorption.

3.4 Carbonation test

Fresh concrete has a pH of at least 12.4, which is the pH of a saturated lime solution. In the presence of carbon dioxide the lime reverts to calcium carbonate, which has a lower pH. If the cement quality deteriorates it is measured by means of an indicator phenolphthalein, which is colourless, but turns red when the pH is greater than 11.4.

On spraying phenolphthalein onto a freshly fractured face, one can determine the depth of deterioration of the cement. Figure 2 shows the cross-section of a sound and deteriorated block.
It is evident that the structural integrity of the deteriorated block was jeopardised, represented by the colourless area, as found in the strength test.

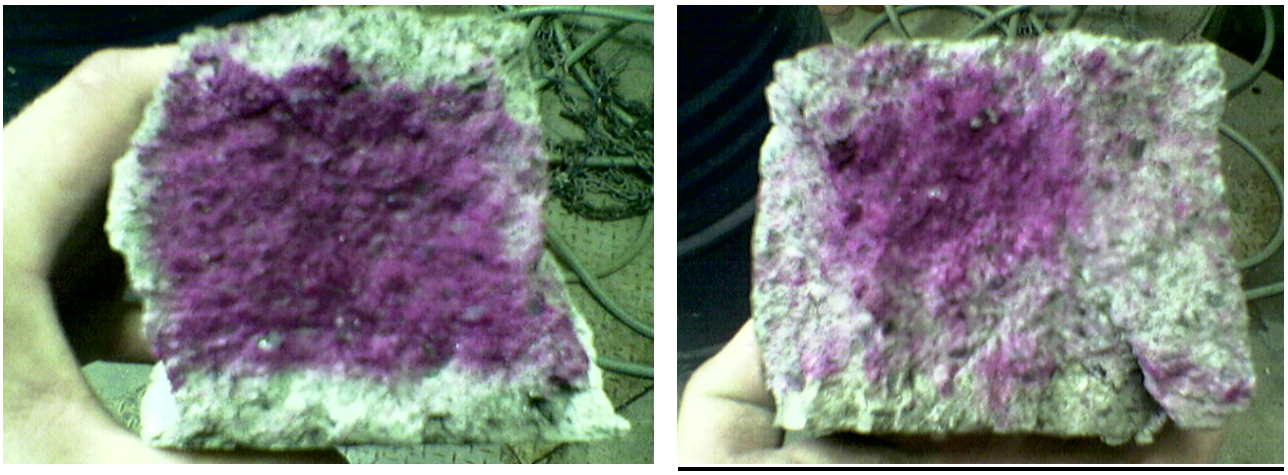

Figure 2. Phenolphthalein test on sound (left) and deteriorated (right) paving blocks

3.5 X-ray fluorescence (XRF) spectroscopy analysis and X-ray Diffraction (XRD)
The XRF and XRD analyses were done to identify differences in the chemical constituents of the various samples. These tests were performed at the University of Pretoria facilities using standard procedures.

The sulphate content of the blocks was low in both tests, which suggests that this is not a problem. The pyrite content is also low. These results did not add any new information to the investigation.

3.6 Cement content analysis
From the calcium oxide content measured in the XRF tests, the cement content was deduced. Obviously the cement that was used to manufacture the blocks was no longer available so a representative value of typical cement was used. The cement content results are given in Table 3.

The relative values between sound and deteriorated blocks at the same site allow comparison. Generally the cement content of deteriorated blocks is lower than the sound blocks, but not in all cases. It is unlikely that the cement content would be that variable for blocks produced at the same time over a period of 15 years, so something has happened to the cement. In absolute terms the cement content is relatively low, but this could be attributed to the use of cement extenders, which are typically of a siliceous nature and indistinguishable from the quartz particles in the XRF analysis.

Table 3. Cement contents and pH in de-ionised water and in hydrogen peroxide

		De-ionised water		Hydrogen peroxide	
SITE	Cement content (%)	pH-value 10 min	pH-value 24 hours	pH-value 10 min	pH-value 24 hours
Virgin aggregate	0	9.5	8.6	2.3	1.7
Welkom SOUND	10.7	11.7	11.6	7.5	10.4
Welkom DET	8.9	11.1	10.7	6.5	8.1
Industrial SOUND	8.9	11.3	11.0	6.6	8.0
Industrial DET	9.5	11.7	11.4	9.0	9.9
Oppenheimer SOUND	9.3	11.4 (11.5*)	11.1 (11.3*)	9.6	9.4
Oppenheimer DET	6.5	9.7 (9.8*)	8.8 (8.8*)	5.5	6.4
Agricultural SOUND	11.0	11.8	11.2	8.7	9.1
Agricultural DET	11.9	11.7	11.1	9.6	9.7
Slipway SOUND	9.8	11.5 (11.4)	11.4 (11.2)	7.0	10.3
Slipway DET	9.6	10.1 (10.1)	9.6 (9.5)	5.7	6.4
New SOUND	10.8	12.2	12.0	9.7	10.4
New DET	9.9	12.2	11.9	9.2	9.4
Average pH – SOUND		11.8	11.4	8.2	9.6
Average pH – DET		11.7	11.3	7.6	8.3

* Duplicate results are shown in brackets

3.6 Acid-base test
The acid-base test allows the evaluation of the weathering products in a neutral and in an oxidising environment. The test procedure was developed by Cruywagen et al (2003). It consists of two separate tests with finely ground material passing the 75 micron sieve. The one is where 5 g of the ground material is placed in 50 ml of de-ionised water, and the other is where 4 g of the ground material is mixed with 80 ml of hydrogen peroxide (30% concentration). The latter represents an

oxidising environment. The pH was measured after 10 minutes and after 24 hours, and the results are shown in Table 3.

In de-ionised water the pH-values are basic (greater than 7) and there is hardly any change in the pH over the 24-hour period, which suggests that no acid is present or generated. In the oxidising environment several of the deteriorated blocks show a significantly lower pH than the sound block, and in some instances much below 7. Of particular interest is that the virgin aggregate has a very low pH, which suggests that acid is produced under the certain conditions. The fact that the blocks have a much higher pH than the virgin aggregate suggests that either the calcareous cement serves as a neutralising agent of the acid, or indicates the highly variable nature of the presence of pyrites. This aspect will be dealt with further in the next section.

4. DISCUSSION OF RESULTS

In paragraph 3 the range of test results were presented. In this paragraph these results will be compared and contrasted to address the problem.

Firstly the effect of density on the strength is considered, and the results for the Agricultural Road are shown in Figure 3. In section 3.1 it was shown that the deteriorated blocks had on average a lower compressive strength than the sound blocks. In Figure 3 it is evident that the strength is related to density. For a lower density, on the one hand there is lower structural bond, but on the other hand greater porosity, which allows more free ingress of moisture and air than if the block was more dense, which could lead to carbonation. This typical result is applicable to all the sites.

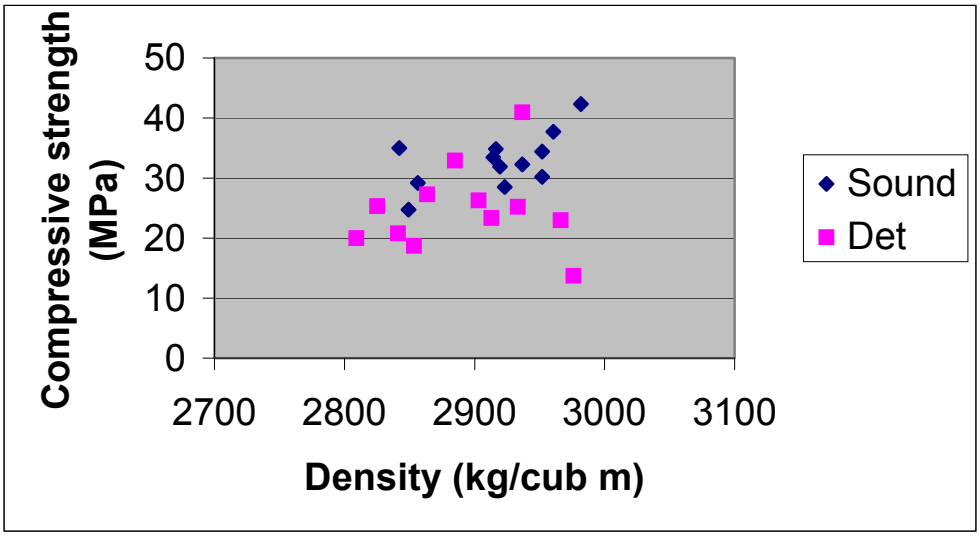

Figure 3. Effect of density on the compressive strength of blocks from the Agricultural Road

This finding is further supported by the effect of water absorption on the compressive strength shown in Figure 4. For a low water absorption, which reflects a high density, the strength is high.

In a further test on the variability of the density and compressive strength 36 blocks manufactured on one pallet were measured. Within the pallet the range of density was 10% (5% below and above the average), and the strength range was 40% of the average. Water absorption was again related to the

density. The production process contributes to the variable nature of the block properties. In the pallet studied the variation in properties was random, and no systematic pattern could be seen.

The following evidence applies to the deteriorated blocks:

- The compressive and tensile splitting strength is lower than the sound blocks;
- The water absorption, and thus porosity, is higher than the sound blocks;
- Carbonation is more extensive, possibly because of the higher porosity, than the sound blocks;
- In some cases the cement content is lower than the sound blocks;
- Under some environmental conditions the aggregate is able to produce sulphuric acid, which could aggravate the deterioration.

As is commonly the case with a problem, it is not a single aspect that causes the problem, but a combination of factors. Porous blocks are inherently weaker than dense blocks. The porous nature allows the ingress of moisture and air, which leads to carbonation of the cement and a possible oxidising environment to produce sulphuric acid. Although the solution would be to produce high-quality dense blocks, the production process has an inherent variability. Cement is probably the highest cost component, and therefore attempts to minimise cement usage will always be made. To ensure that sufficient cement is available to slow down the rate of carbonation, and to provide alkaline material to neutralise acid that may form, care needs to be taken with cement extenders such as fly ash or granulated blast furnace slag that are typically siliceous in nature, and adequate quantities of cement should be used. In the marine environment at least 14% cement, and preferably 18%, should be used to limit deterioration (Visser, 2003).

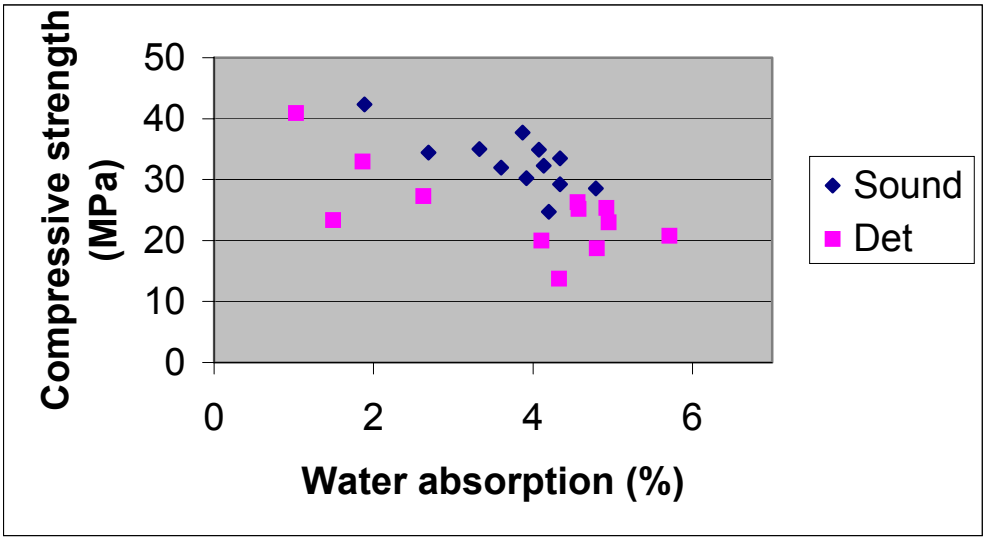

Figure 4. Effect of water absorption on the compressive strength of blocks from the Agricultural Road

5. CONCLUSIONS AND RECOMMENDATIONS

The mechanism of the surface deterioration found in the Free State province in South Africa is the interaction of a number of factors. There is a natural variability of properties, such as compressive and tensile splitting strength, density and water absorption, during the production process. Weaker blocks have a lower density, higher water absorption and therefore porosity that leads to access of air which

may lead to carbonation. The aggregate that is sourced from gold mine dumps has the potential to produce sulphuric acid under certain uncontrollable environmental conditions. This could aggravate the deterioration.

Although many of these aspects are uncontrollable, some may be limited. Careful control of the production process could reduce variability. Even when the porosity is high, sufficient cement would reduce the rate of carbonation. Adequate cement content is also necessary to neutralise any sulphuric acid that may form as there is no other source of aggregate which is available. Care should be taken in using cement extenders such as fly ash or granulated blast furnace slag, as these are of a siliceous nature and do not provide constituents necessary to neutralise the acid. Higher cement contents used historically, such as on the Slip Road, may again be necessary.

The process of evaluation described in this paper could also be used to evaluate recycled materials whose constituents may be unknown, and whose influence on the long-term durability could be suspect.

6. ACKNOWLEDGEMENTS

Mr. Henk van der Walt performed the tests as part of his final year research project, and his assistance on this project is gratefully acknowledged. Concor Technicrete, and in particular Mr Taco Voogt, supported the project and made it possible to carry out the test regime, for which we are truly thankful.

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